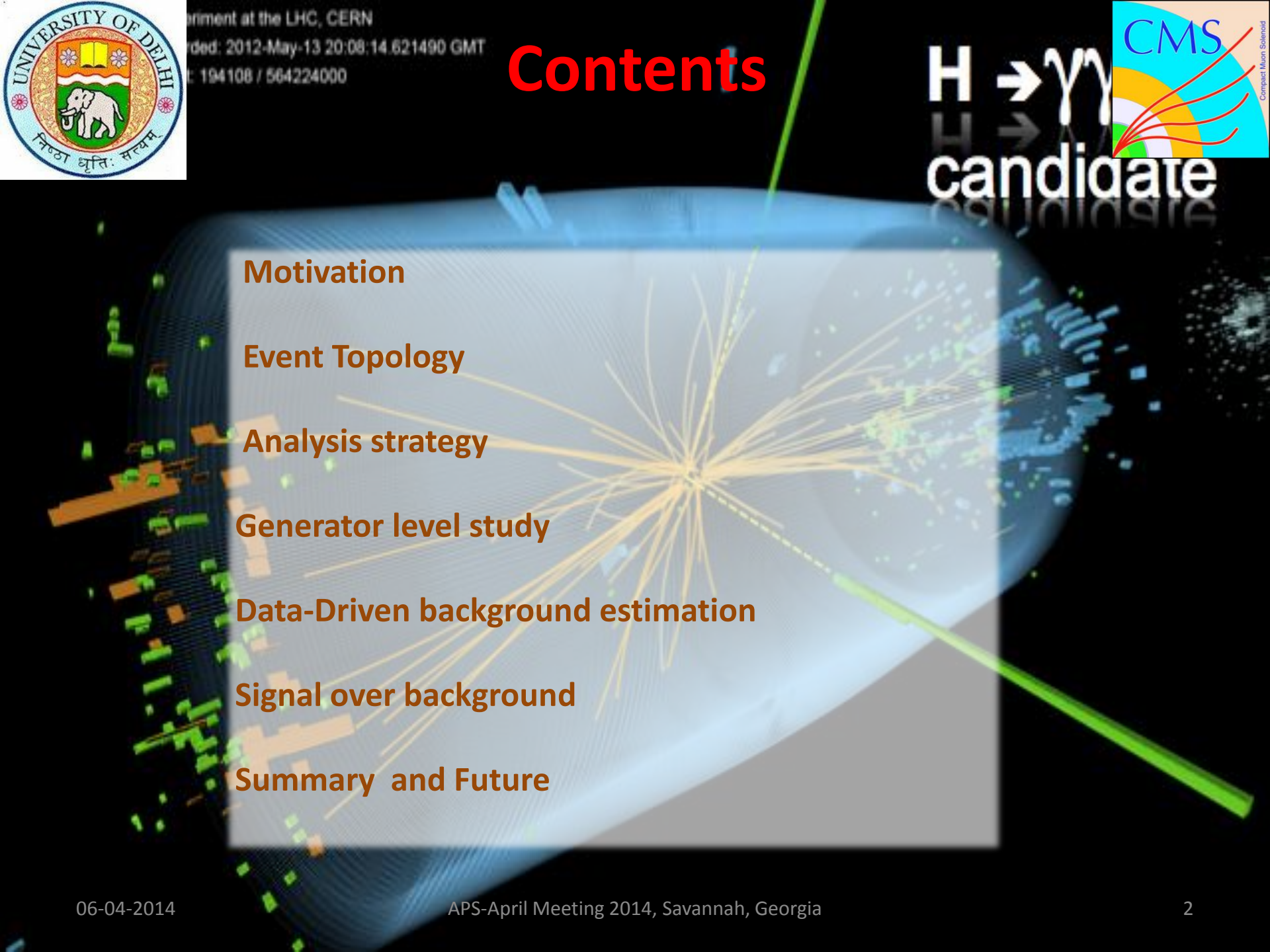
Probe of WW production in vector boson fusion topology

Ajay Kumar

Fermilab/University of Delhi

On behalf of CMS Collaboration

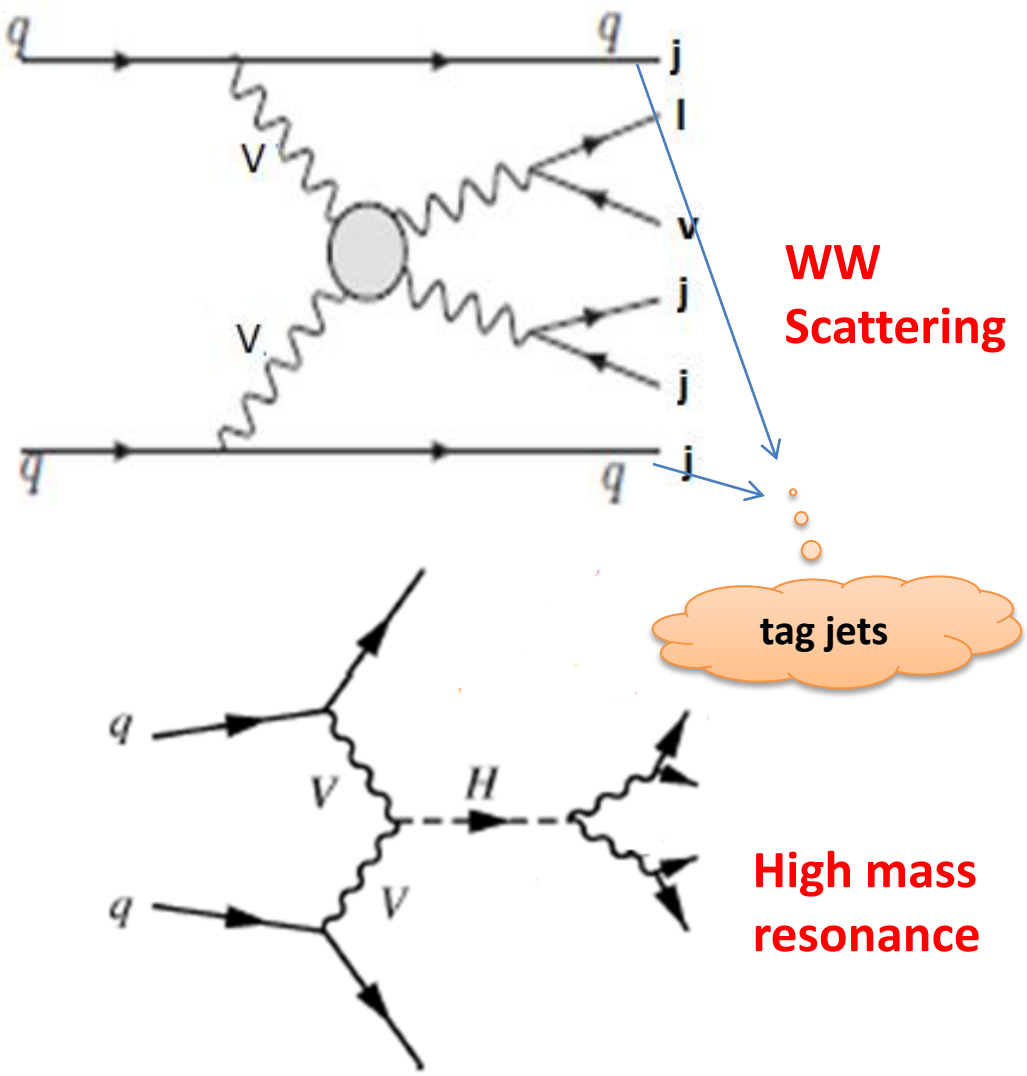


Contents

- Motivation
- Event Topology
- Analysis strategy
- Generator level study
- Data-Driven background estimation
- Signal over background
- Summary and Future

Motivation

- **Electroweak Symmetry Breaking.**
- sensitive to new physics, e.g. anomalous **triple** and **quartic** gauge Couplings.
- **VBF WW not yet measured experimentally**

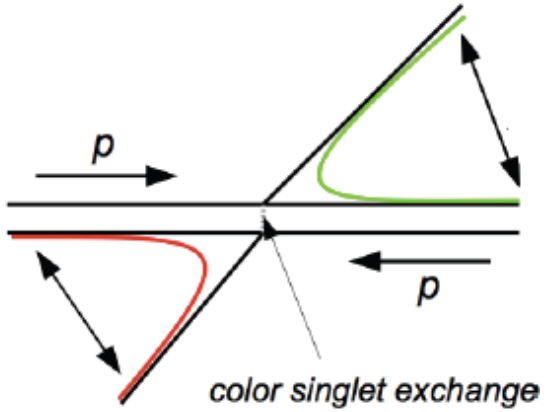


Event Topology

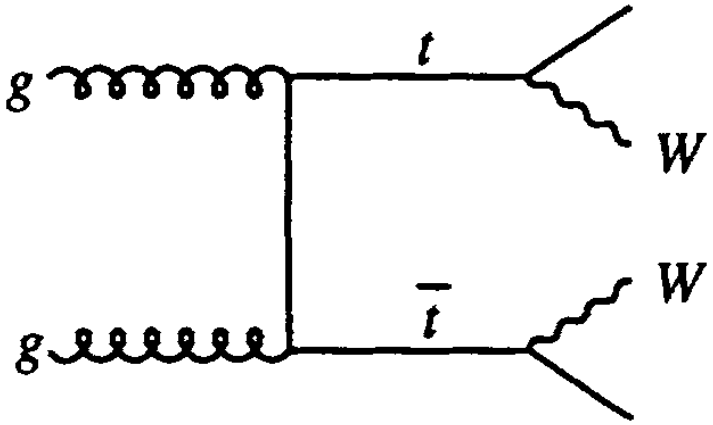
Process: q $\bar{q}$→WW+2Tagjets→Lepton+MET+2jets+2Tagjets

Signal:

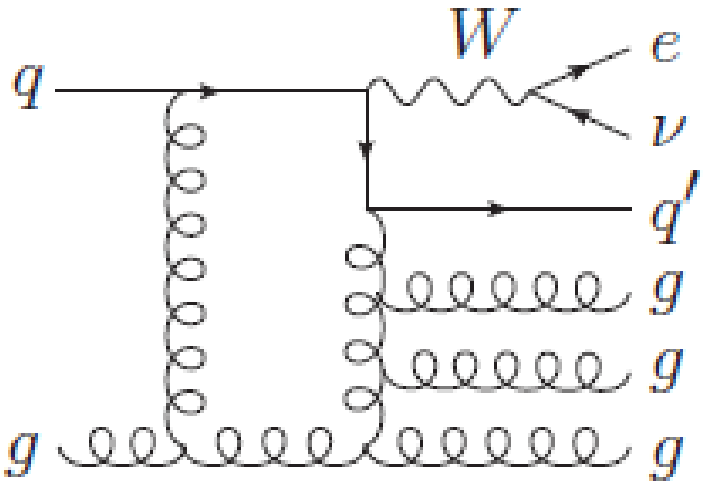
- **forward** and **backward** jets.
- **Electroweak process**



Backgrounds:



TTbar: real W



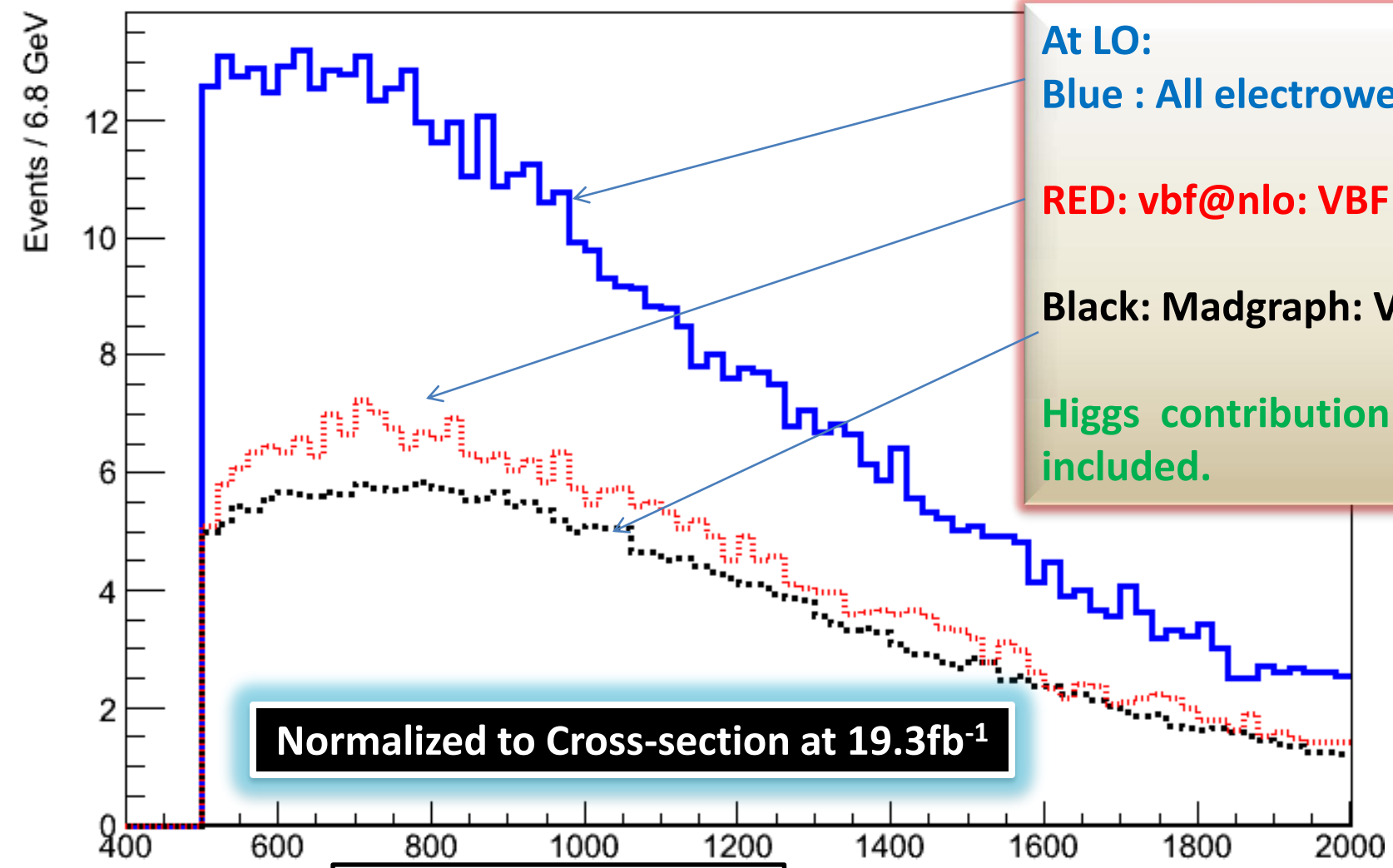
Wjets: Large Cross-section

Analysis Strategy

- Isolated high pt lepton, missing energy and AK5 jets .
- Tag forward jets: Mjj ^{inv} >500 GeV && eta gap >3.5 : huge reduction in QCD
- Require $W_{lep} \rightarrow l\nu$ & $W_{had} \rightarrow qq$ on-shell
- Reconstruct $m_{WW} = m_{l\nu qq}$ by reconstructing neutrino P_Z from W-mass Constraint
- Define signal region m_{jj} = [65,95] GeV
- We have very small S/B ratio: so huge systematic error
- So, Data driven methods
  - 1. to estimate Wjets from hadronic W side bands
  - 2. to estimate TTbar from top enriched sample
  - (binned template fit)

Generator level study

With event selection similar to reco Preselection



At LO:

Blue : All electroweak O(α^6)

RED: vbf@nlo: VBF WW

Black: Madgraph: VBF WW

Higgs contribution included.

Normalized to Cross-section at 19.3fb^{-1}

Tag jets invariant mass

Data-Driven background estimation(1/2)

1.) W+Jets:

Hadronic W invariant mass:

Choose control region:

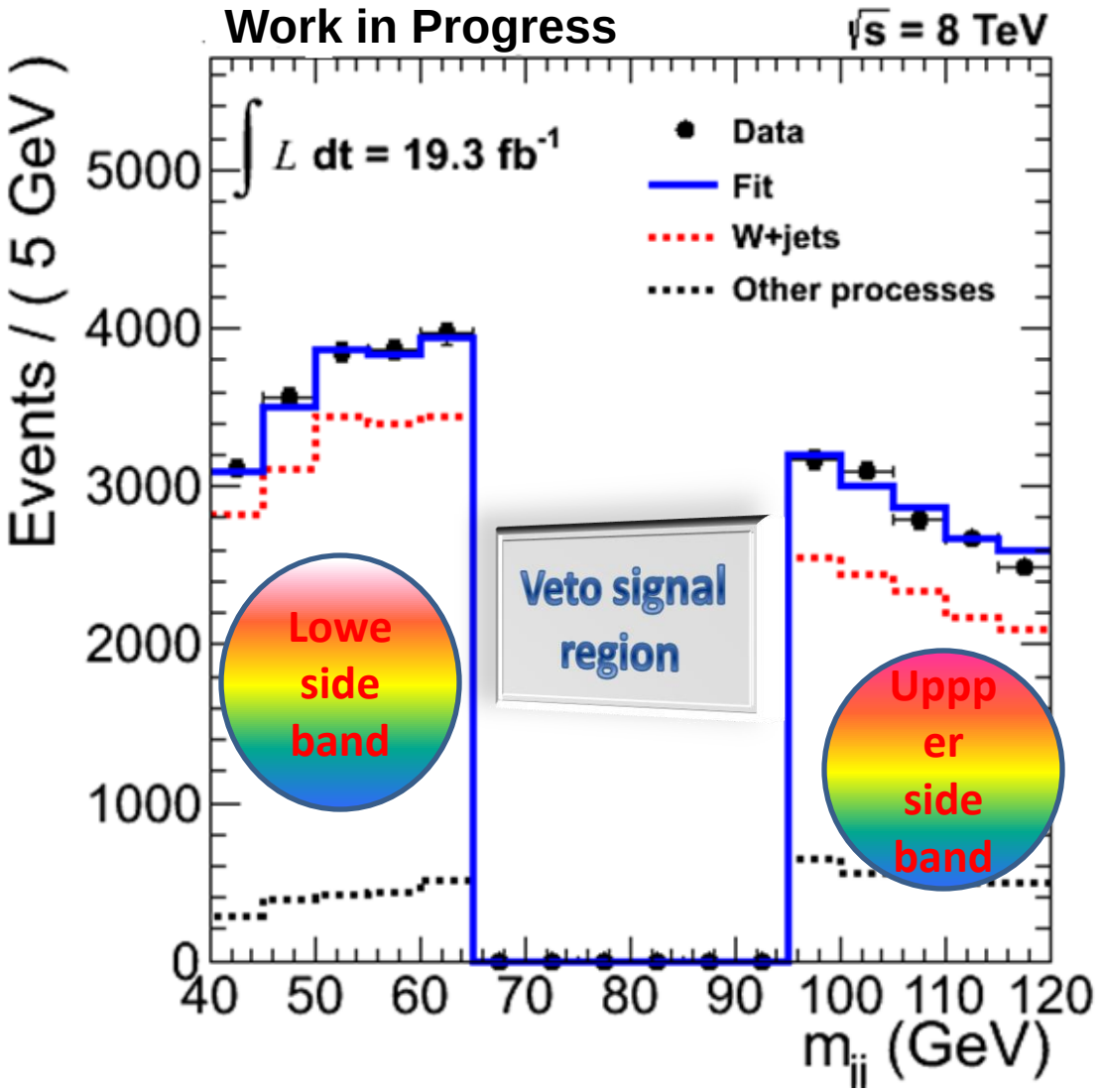
Lower side band:

$40GeV<m^{jj}<60GeV$

Upper side band:

$95GeV< m^{jj} <120GeV$

Template fit to data



Data-Driven background estimation(2/2)

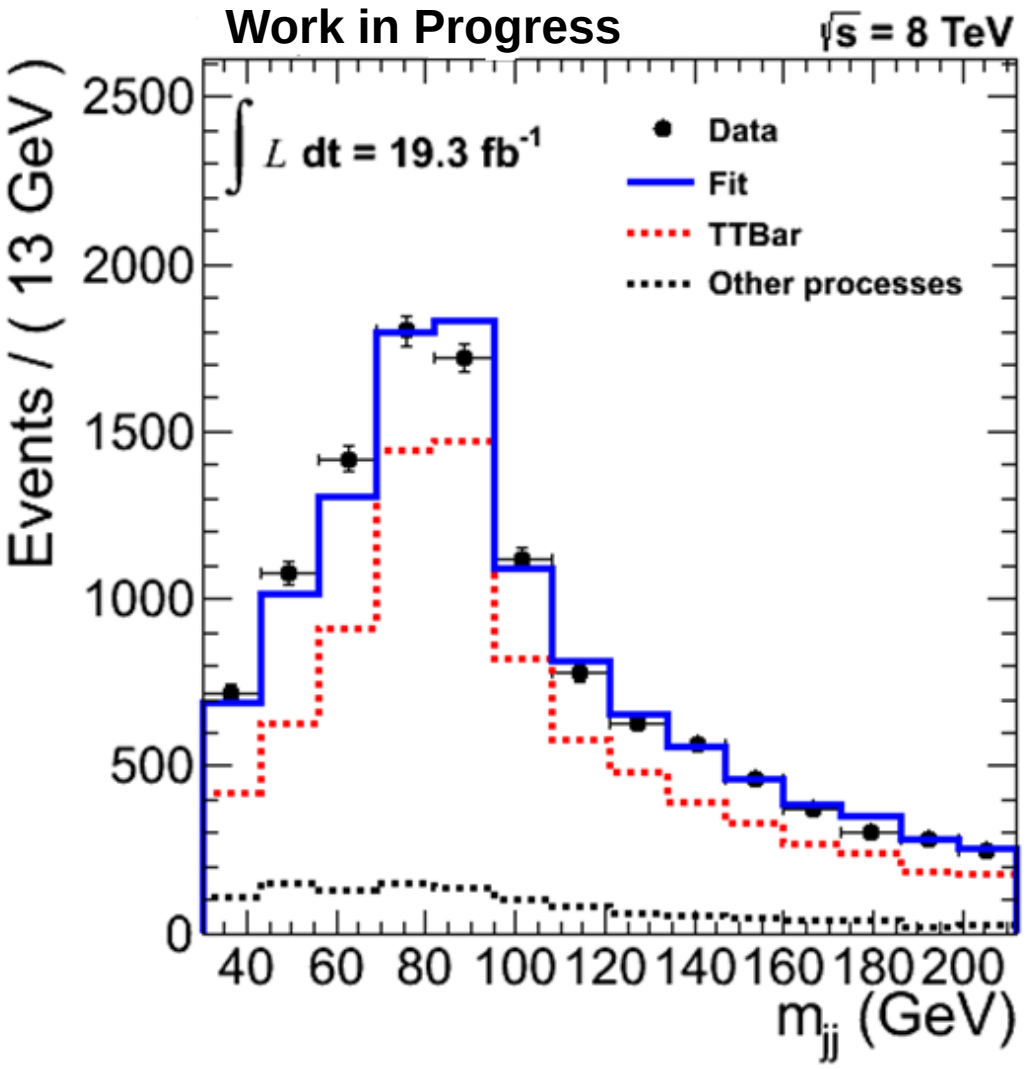
2). TTbar estimation:

Variable:
Hadronic W invariant mass
from antibtagged jets

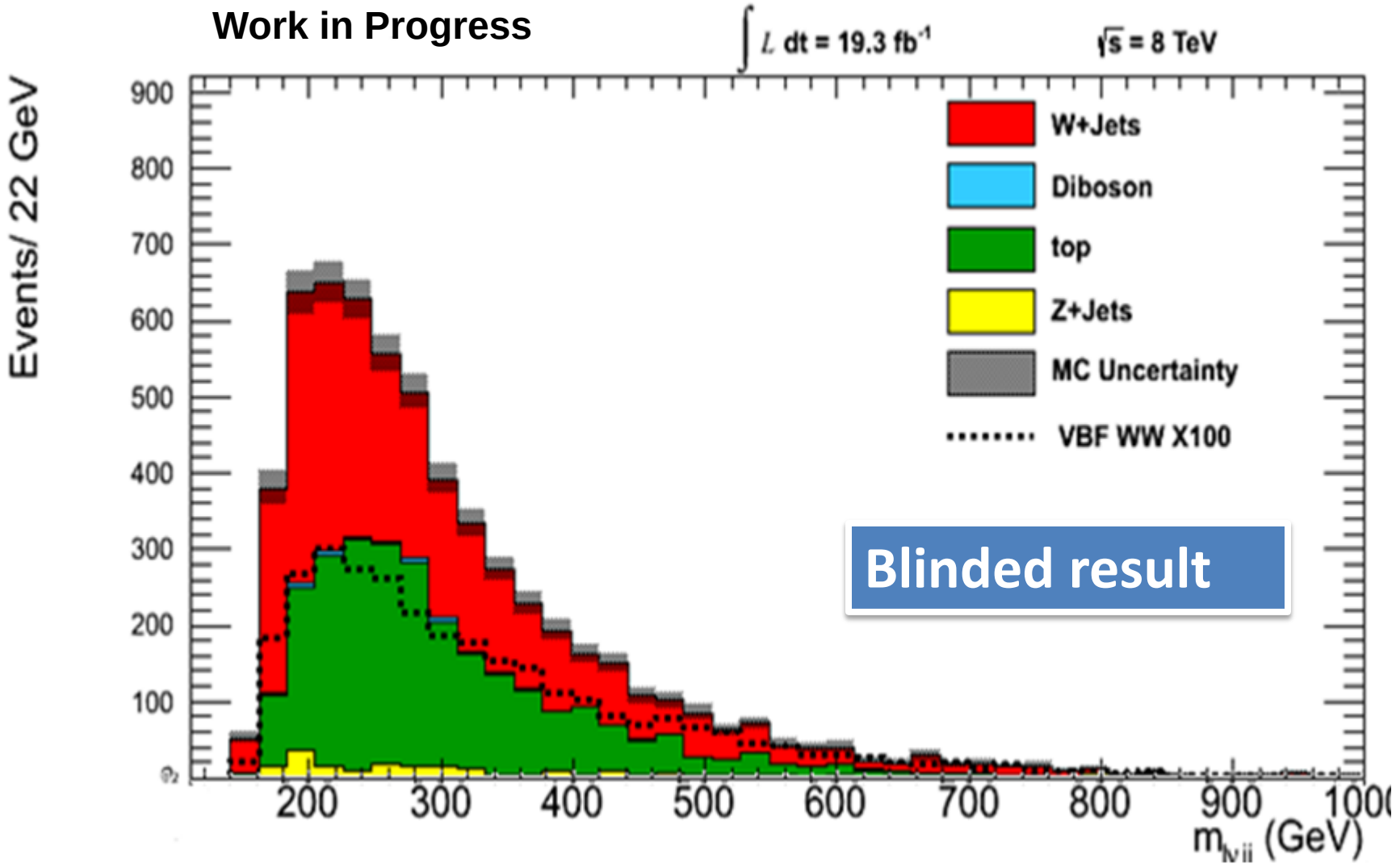
Top enriched events:

- **2tag jets,**
- **2 antibtagged jets**
- **and 2 btagged jets.**

Template fit to data



Signal over background



Summary

Future where are we heading…

1). A sensitivity study to WW+2jets production at 8TeV has been performed.

2). Advance techniques like quark gluon likelihood, normal likelihood being explored.

3). We estimate major backgrounds in data driven way.

4). systematic error estimation in progress.

5). From theoretical prediction, at 13-14 TeV we need data above ~300 fb^{-1} to have conclusive result. This is work in process for WW scattering, which will be sensitive at RUN 2 of LHC running.

Thank you for your Attention !

Sample and Software

CMSSW_5_3_2_patch4 for both Data and MC Processing

Trigger: Single Lepton trigger:

Muon channel : ('HLT_IsoMu24_*','HLT_IsoMu30_*')

Electron channel: ('HLT_Ele27_*','HLT_Ele32_*')

Background Sample	Cross-section (pb)
Signal: VBF WW	0.0776*1.5
Bkg:	
W1jets,W2jets, W3jets, W4jets	**5400,** 1750.0, 510.0 ,214.0
Z+jets	**3503**
WW	**57.1**
WZ	**32.3**
ZZ	**8.3**
t¯t+jets	**225.2**
t/¯t+jets (t-channel)	**85.5**
t/¯t+jets (s-channel)	**5.65**
t/¯t+jets (tW-channel)	**22.4**

Data Samples (8TeV)

Dataset name	Run range
/SingleMu/Run2012A-13Jul2012-v1/AOD	190456-193621
/SingleElectron/Run2012A-13Jul2012-v1/AOD	
/SingleMu/Run2012A-recover-06Aug2012-v1/AOD	190782-190949
/SingleElectron/Run2012A-recover-06Aug2012-v1/AOD	
/SingleMu/Run2012B-13Jul2012-v1/AOD	193833-196531
/SingleElectron/Run2012B-13Jul2012-v1/AOD	
/SingleMu/Run2012C-24Aug2012-v1/AOD	198022-198913
/SingleElectron/Run2012C-24Aug2012-v1/AOD	
/SingleMu/Run2012C-PromptReco-v2/AOD	198934-203746
/SingleElectron/Run2012C-PromptReco-v2/AOD	
/SingleMu/Run2012D-PromptReco-v1/AOD	203894-208686
/SingleElectron/Run2012D-PromptReco-v1/AOD	

This correspond to Total Integrated Luminosity : 19.3 fb^{-1}

Event Selections

Selection of Jets: for each jet Pt >30GeV: |eta | <4.7

From collection of jets, Choose first tag jets from merged jets collection sorted in pt in with default tag jet selection, if there are more than one such pair then choose the one with Highest dijet mass of tag jets , From remaining jets choose the leading two jets as W jets

Default tag jet selection: Eta1*Eta2<0, Eta1-Eta2>3.5 and TagJet Invariant mass >500

Muon:

W_muon_pt>25.

&& fabs(W_muon_dz000)<0.02

&& fabs(W_muon_dzPV)<0.5

&& fabs(W_muon_eta)<2.5

MET:

event_met_pfmet>25.

Additional cuts:

3. hvbf_lv_m >30. (Leptonic W transverse mass)

4. hvbf_wjj_m >65 && <95 (hadronic W mass)

Physics Objects

Muons : Using the official mu-POG recommendation

- **https://twiki.cern.ch/twiki/bin/view/CMSPublic/SWGuideMuonId**
- **Using "thigh" and "loose" (for veto) definitions**
- **PF based isolation with PU correction**

Electrons : Using the official e/γ-POG recommendation

- **MVA ID: https://twiki.cern.ch/twiki/bin/viewauth/CMS/MultivariateElectronIdentification**
- **Conversion rejection**
- **PF based isolation (ΔR0.3) with PU correction with Effective Area**
- **Tight electron: WP80 triggering MVA**
- **Veto : WP90 non-triggering MVA**
- **WP definitions: https://twiki.cern.ch/twiki/bin/view/Main/HVVElectronId2012**

Jets:

- **AK5 PF jets with CHS, JEC: L1,L2,L3(residual for data)**
- **PU jet ID: https://twiki.cern.ch/twiki/bin/view/CMS/PileupJetID**

Missing Transverse Energy:

- **PF MET : type-I and shift (phi modulation) corrections**

Signal generation

The signal generation is a key aspect of the study since a precise knowledge of the $\sigma(pp \rightarrow VVjj)$ on the whole VV invariant mass spectrum is essential.

1. Madgraph process:

generate p p > w+ w- j j QED=4 QCD=0, w+ > l+ vl, w- > j j @1
add process p p > w- w+ j j QED=4 QCD=0, w- > l- vl~, w+ > j j @2
add process p p > w+ z j j QED=4 QCD=0, w+ > l+ vl, z > j j @3
add process p p > w- z j j QED=4 QCD=0, w- > l- vl~, z > j j @4

Cross-Section: 110.05 fb

2. VBF@NLO:

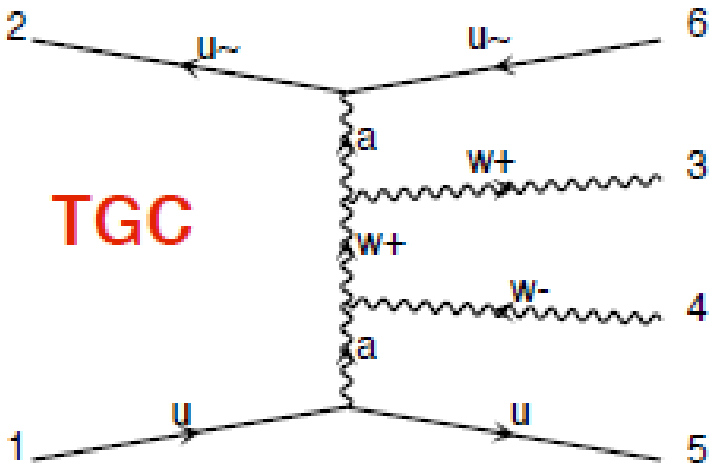
pp -> W+ W- jj -> q q~ l- vl~ jj W pair + 2 jets production in vector boson fusion with subsequent decay of the W+ to quarks (and W- to leptons and the W- to quarks and W+ to leptons.)
The Higgs contribution is included. Process is implemented at LO and NLO QCD.
PROCESS: 202 : p p --> W+ W- jj --> ve/mu e/mu+ q q~ jj with leading order hadronic decay of one vector boson

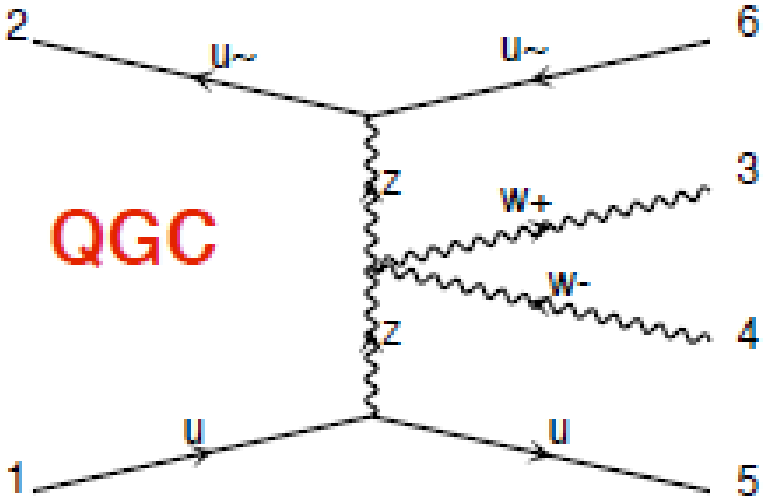
Cross-Section: 39.394fb

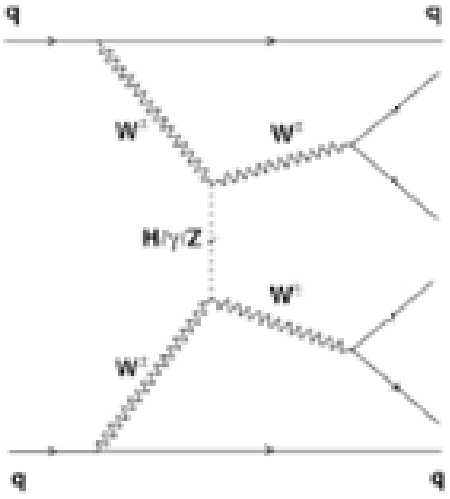
3. Phantom: It is a tree level MC event generator for six fermions final state at pp collider at $O(\alpha^6_{EM})$

EW of order of 6 : Cross-Section: 77.6fb

Signal definition

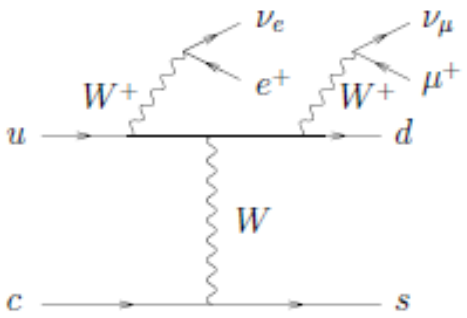




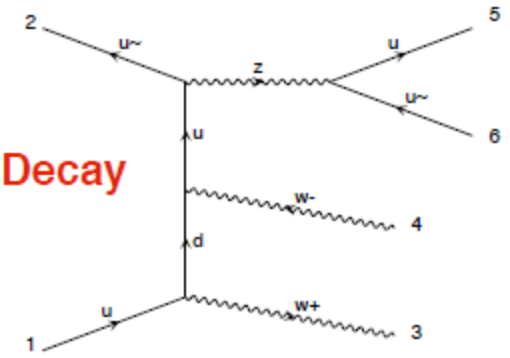


VV scattering through Higgs

Brem-like



Decay



Scattering Signal

At a hadron collider such as the LHC, a WW scattering event is characterized by a W pair produced with a pair of forward and backward tagging jets.
we can define the new physics signal as the event excess in WW scattering over the SM prediction with a light Higgs (mh 125 GeV)

Signal = $(pp \rightarrow jjWW)^{\text{new physics}} - (pp \rightarrow jjWW)^{SM}$

Although a 125 GeV Higgs-like particle has been discovered at the LHC, a sizable excess in WW scattering can still emerge if the new particle has non-SM couplings to W and Z, and cannot fully unitarize WLWL scattering. This happens in a generic class of composite Higgs models, namely, the Strongly Interacting Light Higgs (SILH) models.

DeltaR=0.5	With Max 4 jets	With max 5 Jets	With Max 6 jets	With Max 7 Jets	With Max 8 Jets
Exactly 3 matching jets	14941/31396 =0.47	13887/31396 =0.44	13689/31396 =0.436	13648/31396 =0.434	13640/31396 =0.434
Exactly 4 matching jets	*11119/31396 =0.35*	12590/31396 =0.40	12868/31396 =0.41	12926/31396 =0.41	12936/31396 =0.41

The gain in efficiency on applying pt cut on genjets: 35% -> 57%

DeltaR=0.5	With Max 4 jets	With max 5 Jets	With Max 6 jets	With Max 7 Jets	With Max 8 Jets
Exactly 3 matching jets	11690/17052=0 .68	10835/17052=0 .635	10693/17052=0 .63	10658/17052=0 .625	10656/17052=0 .63
Exactly 4 matching jets	9692/17052=0. 57	10956/17052=0 .64	11190/17052=0 .656	11242/17052=0 .659	11249/17052=0 .659

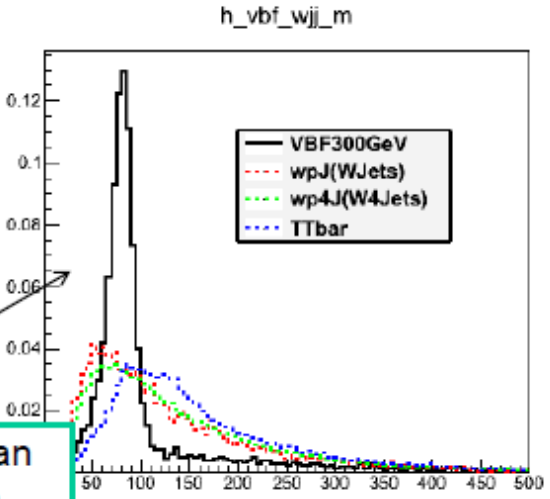
The gain in efficiency looking at more than 4jets is sizable 57%→66%

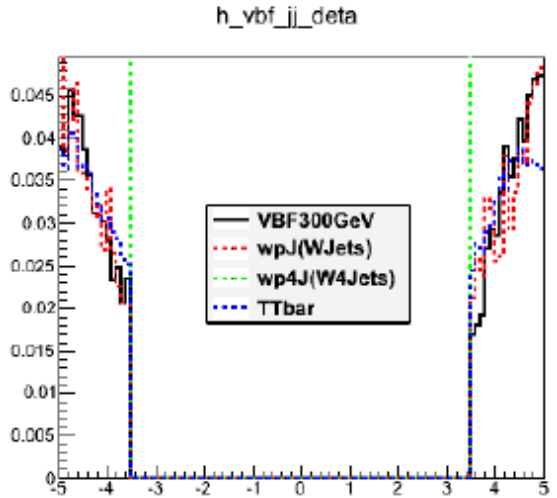
First method

A) search the pair of jets that satisfy the default tag selection, if more then one then keep the one with largest Mjj

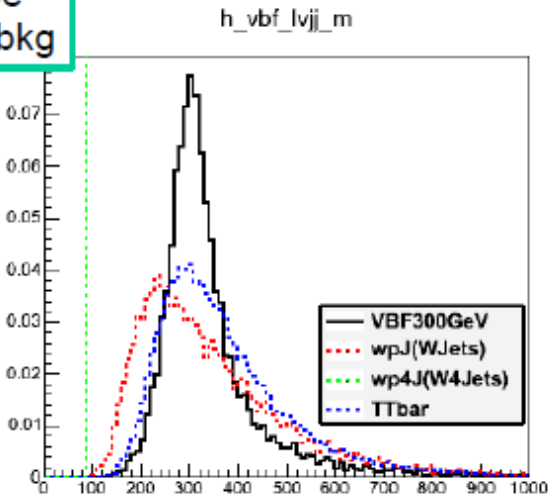
B)Between the remaining jets chose the 2 with highest PT as the ones from W

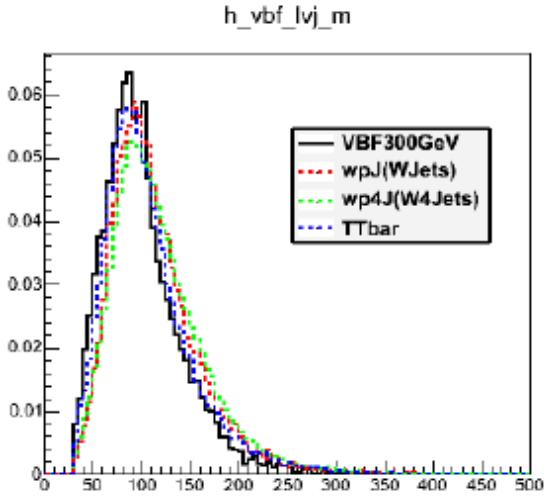
method1





Here we can clearly see diff in shape of sig and bkg



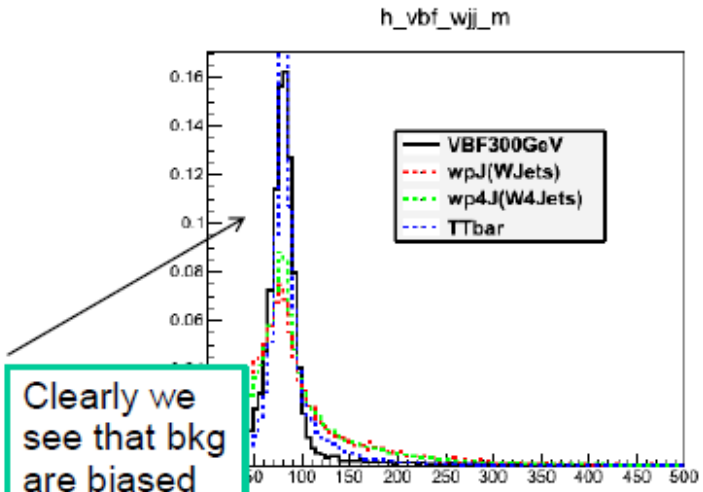


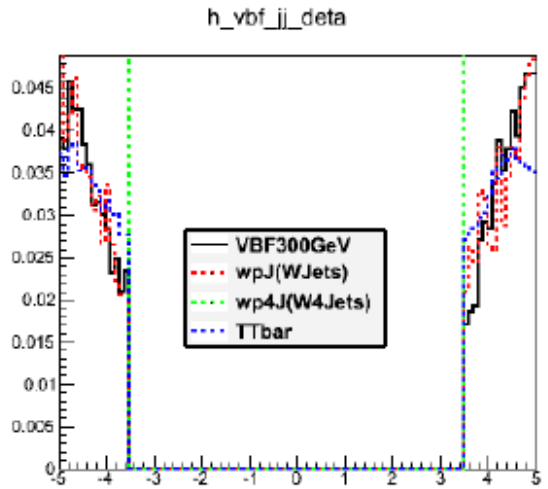
Second method

A) same as before

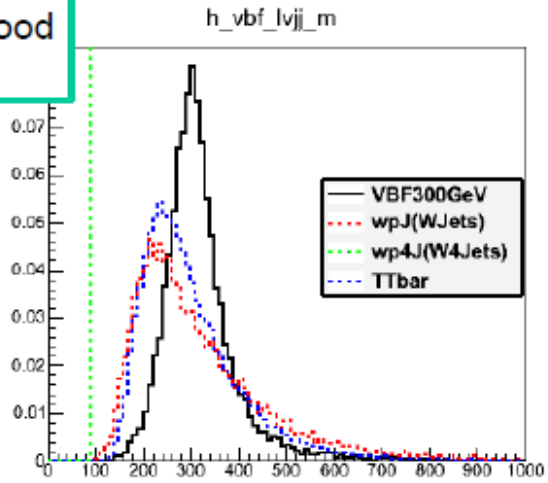
B) Between the remaining jets chose the 2 with mjj more similar to mW as the ones from W

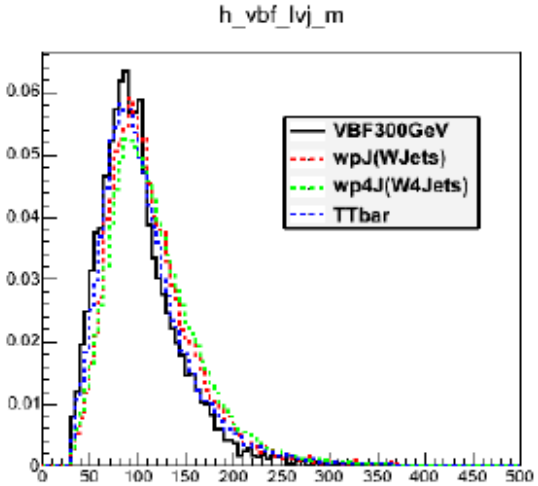
method2



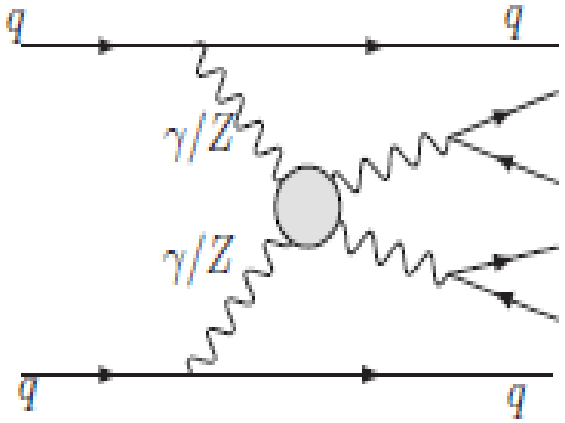


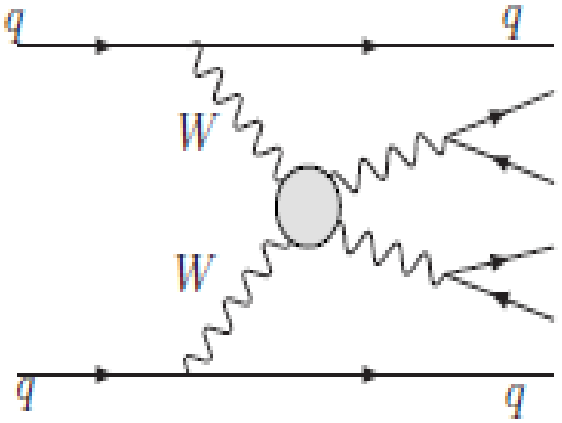
Clearly we see that bkg are biased in method2 so, not good choice

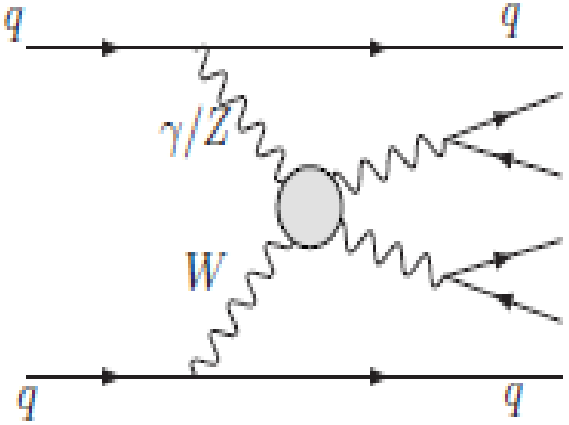




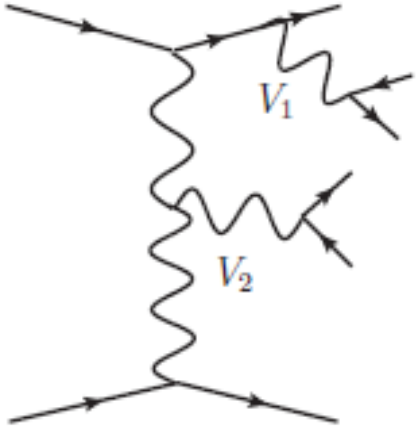
Phantom contributors

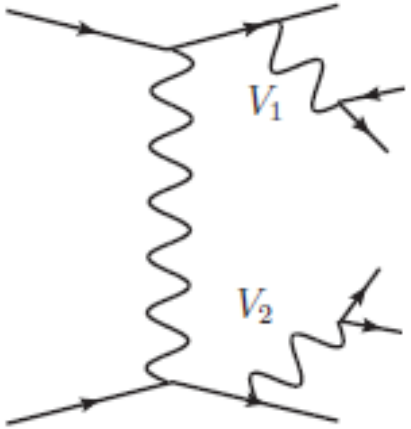


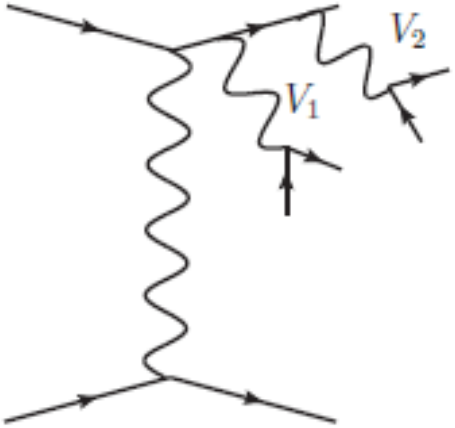




EW6

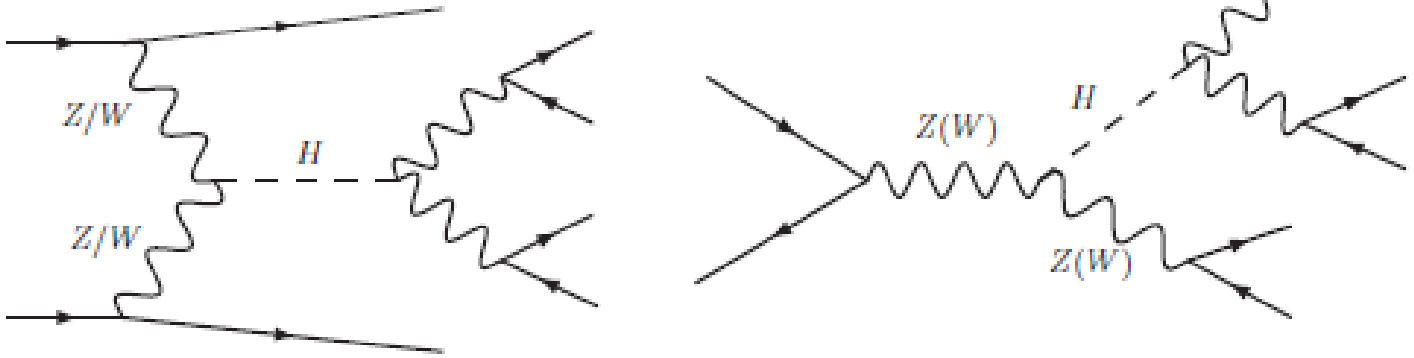


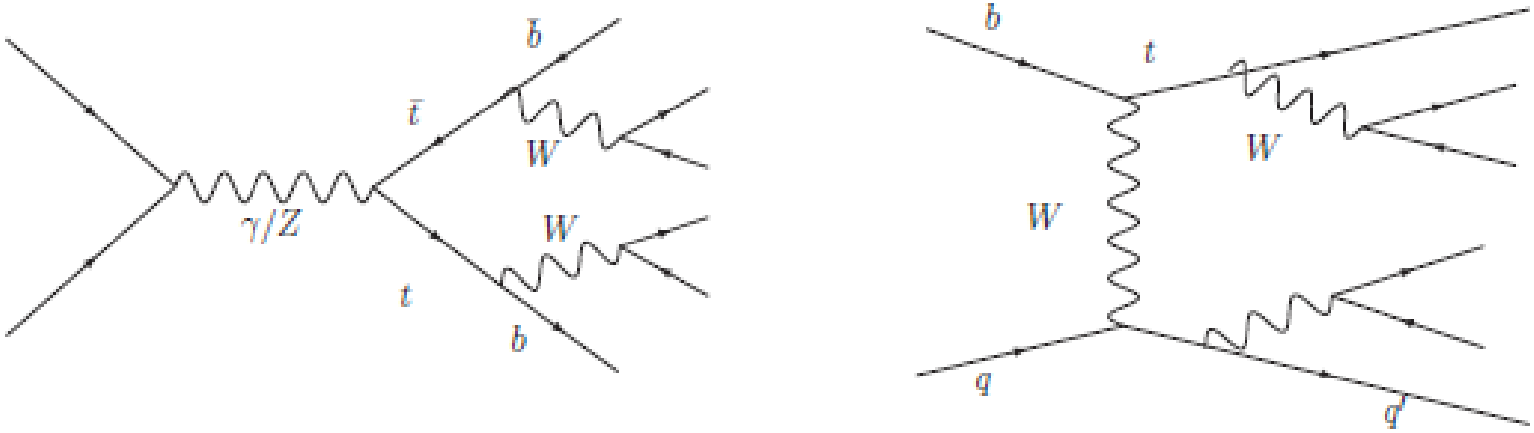




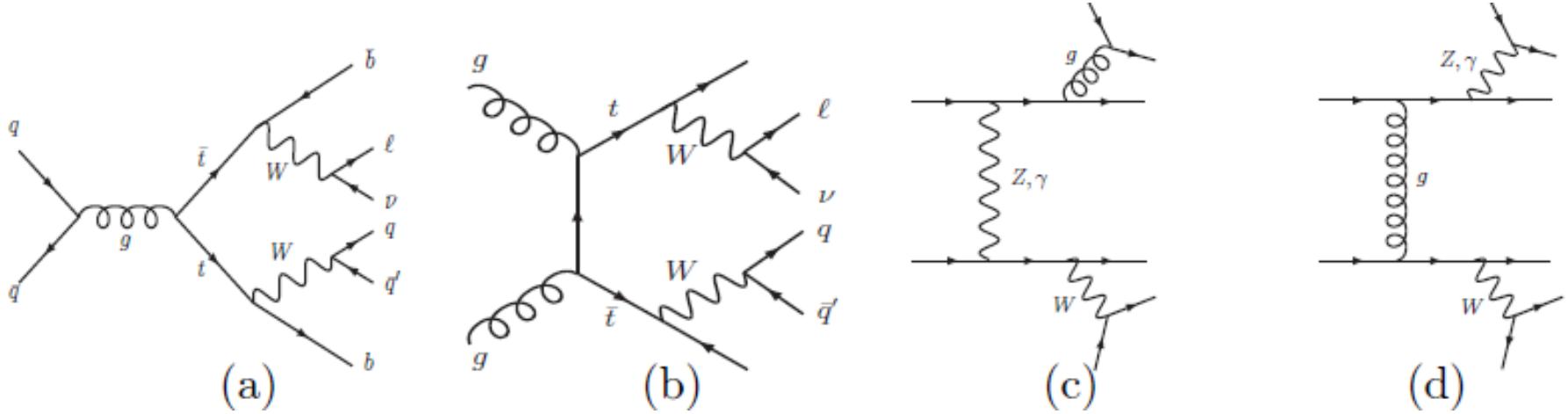
Phantom contributors

EW6



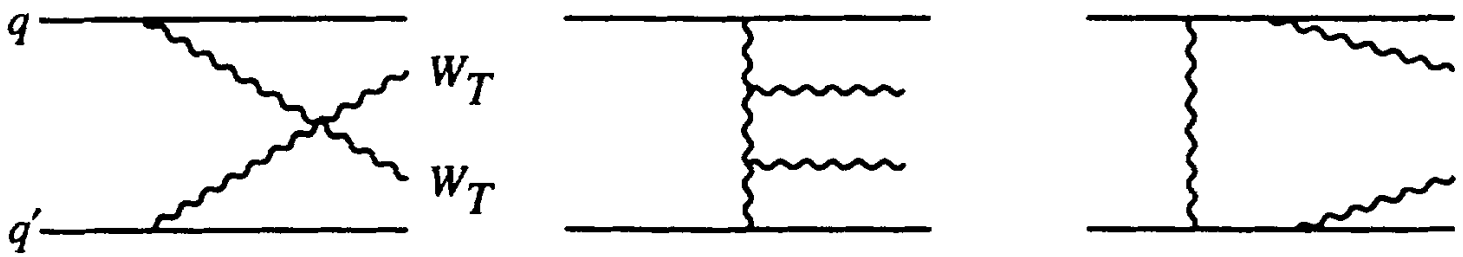


Strongly interacting processes

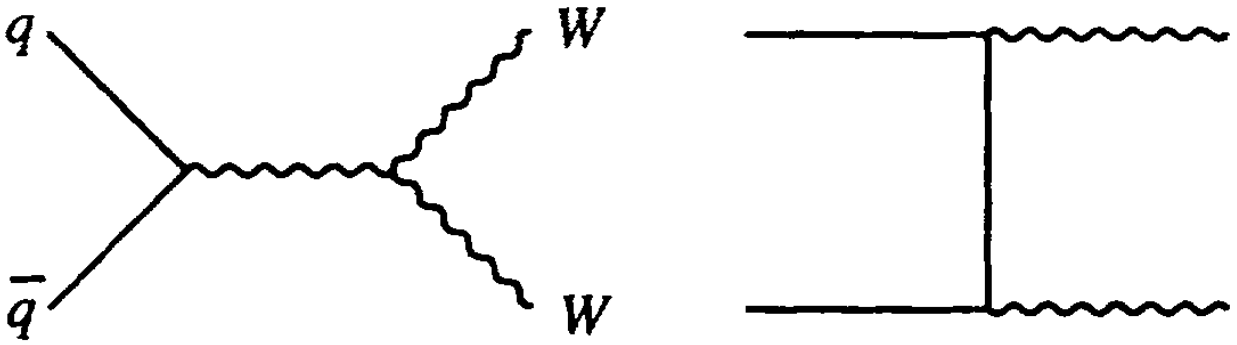


QCD : (a) and (b) ttbar, (c), (d) VV+2Jets

backgrounds

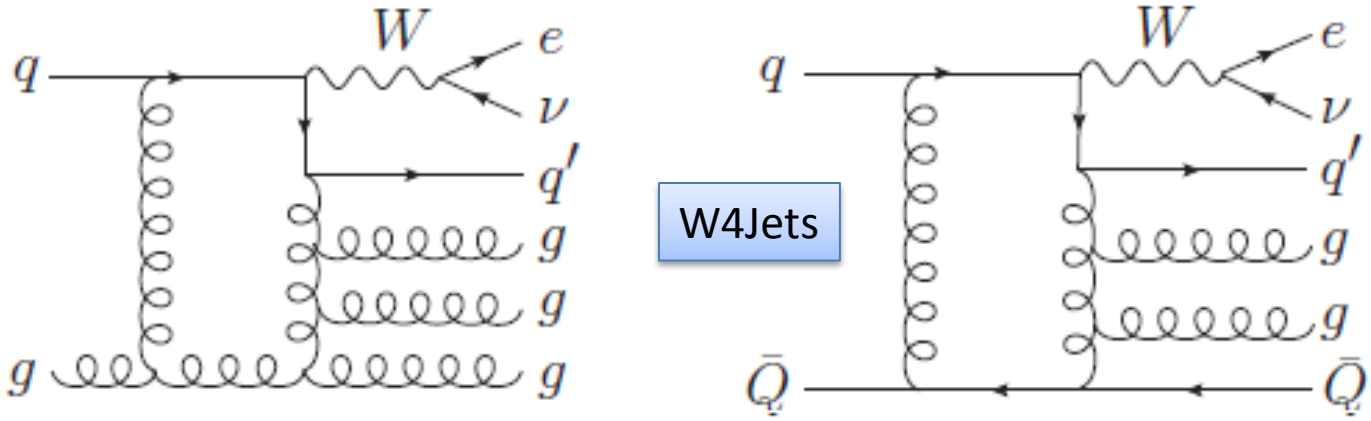


Irreducible SM backgrounds: (scattering and non scattering diagram (EW & QCD)

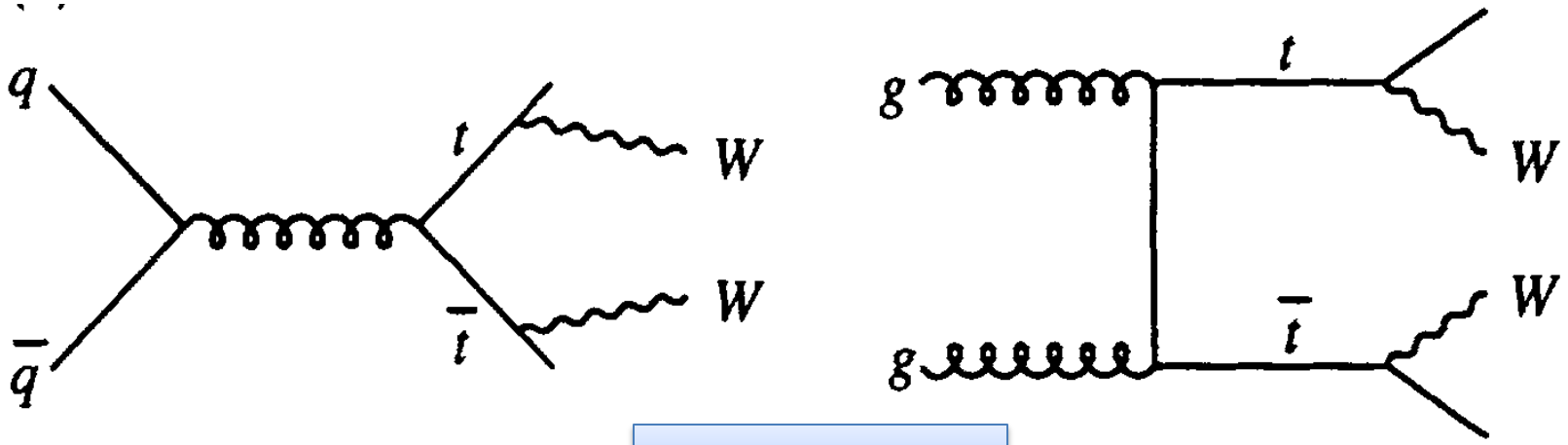


qq annihilation, manageable on requirement of tag jets

Major backgrounds



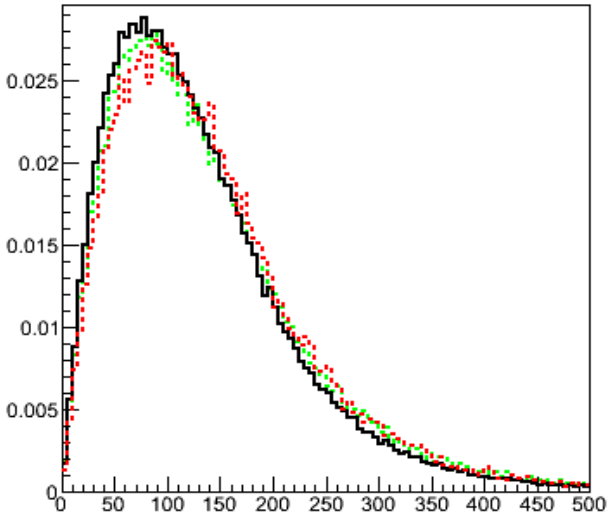
W4Jets



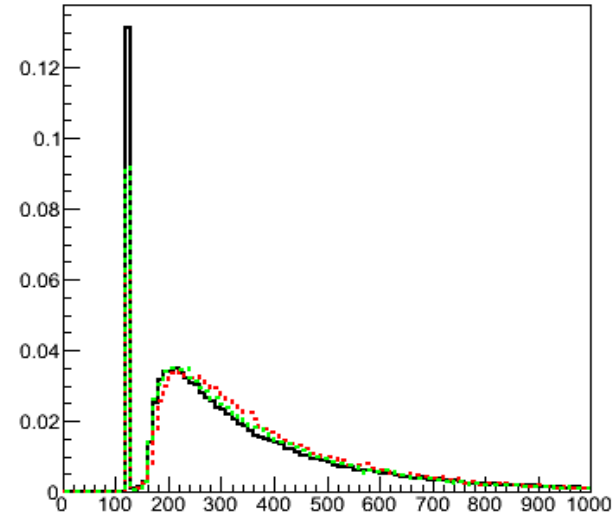
Top production

Shape comparison : Normalized to area

h_vbf_lvjj_pt

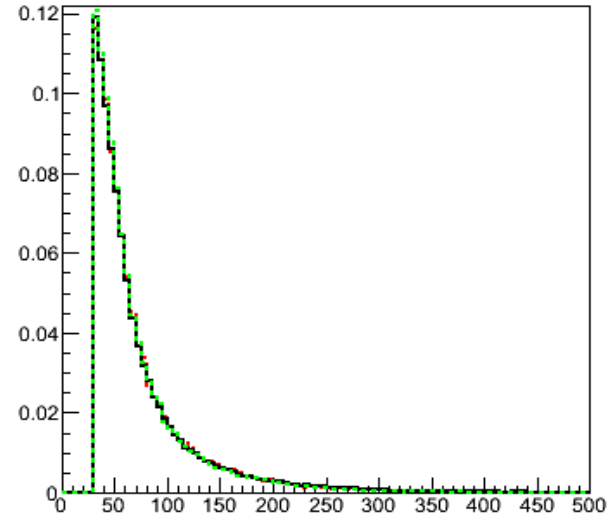


h_vbf_lvjj_m

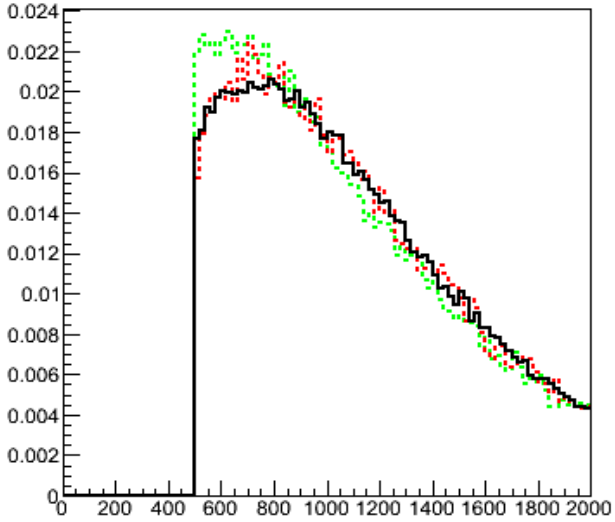


Top event vetoed completely

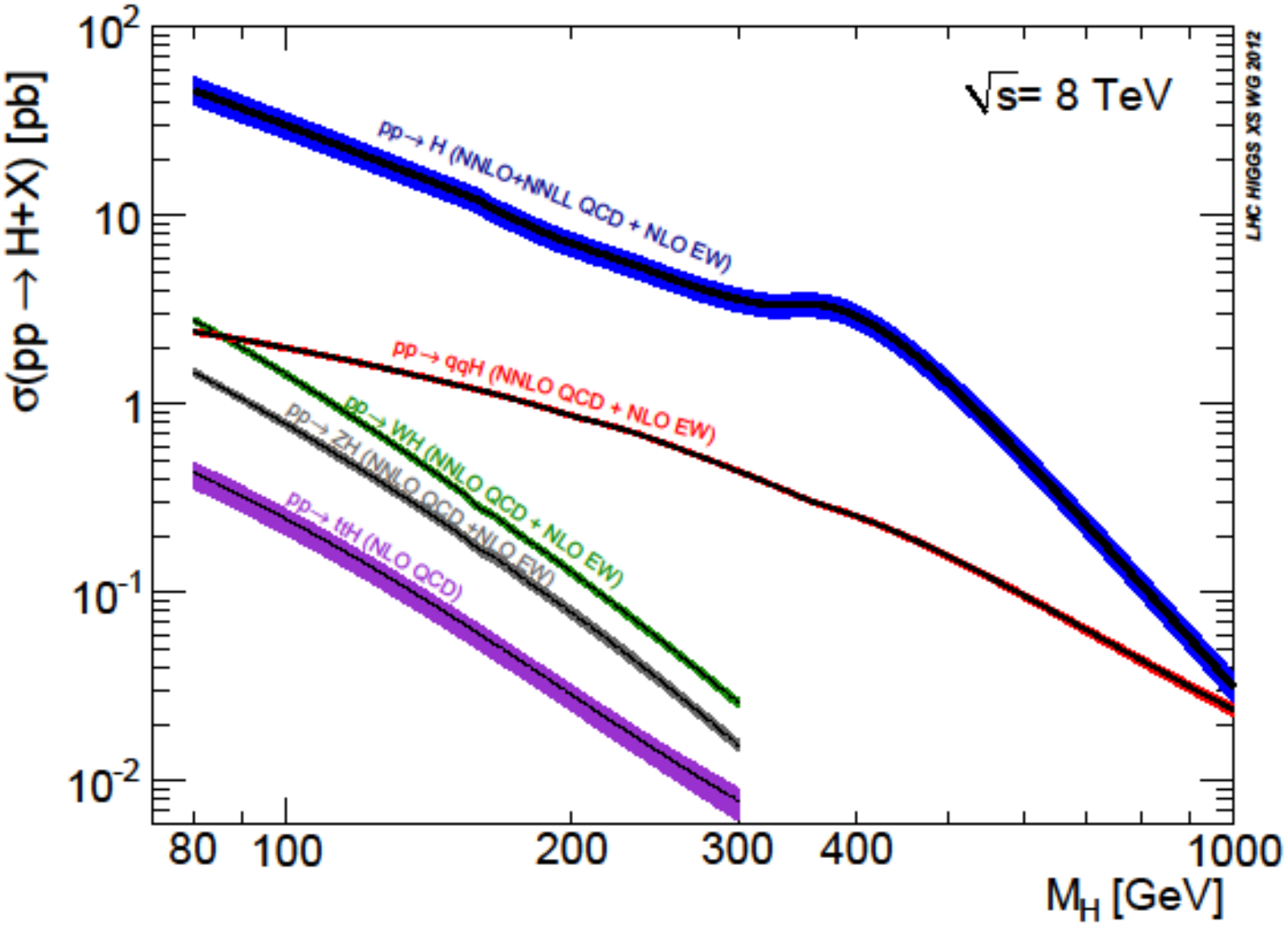
h_vbf_l_pt



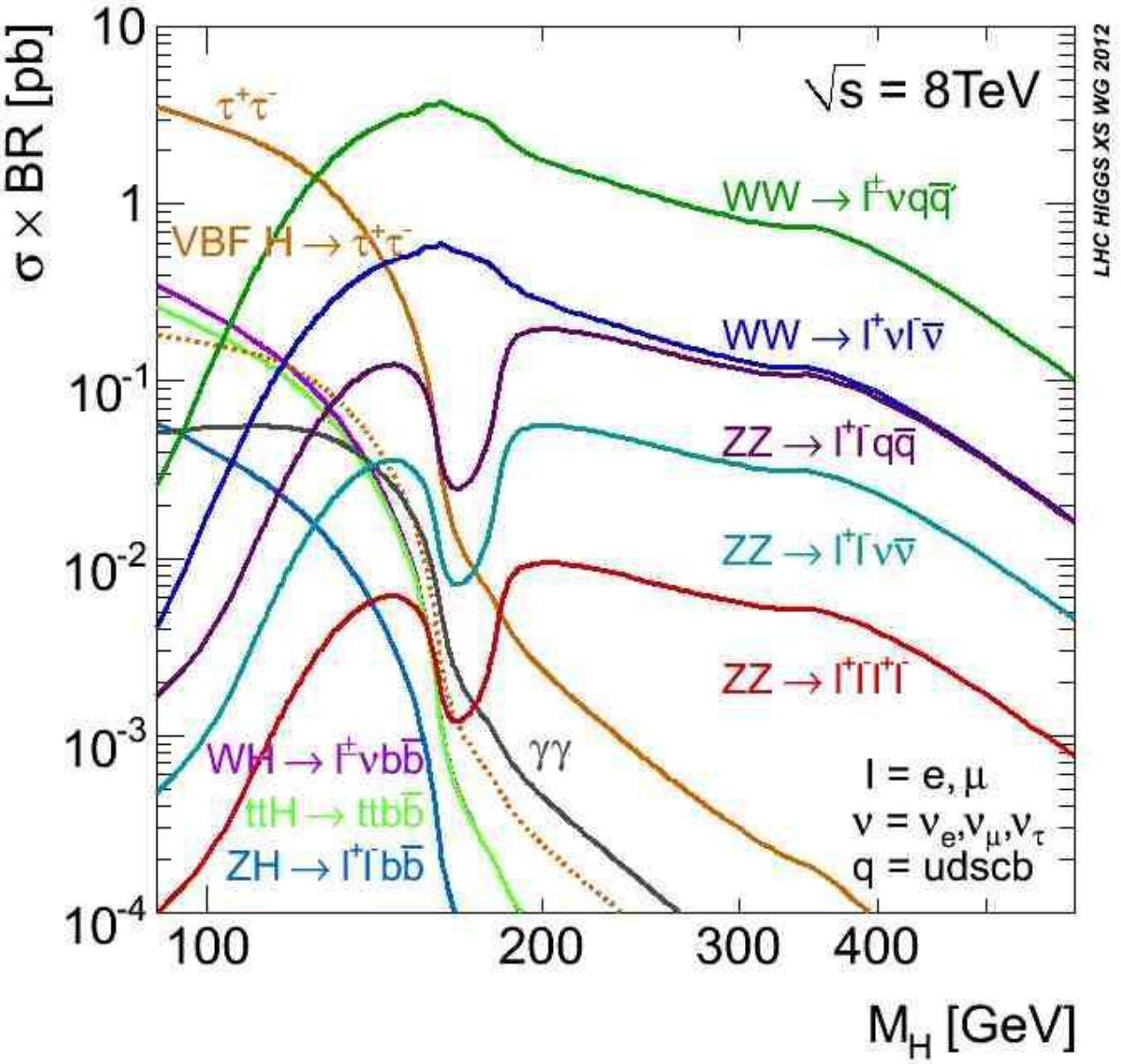
h_vbf_jj_m

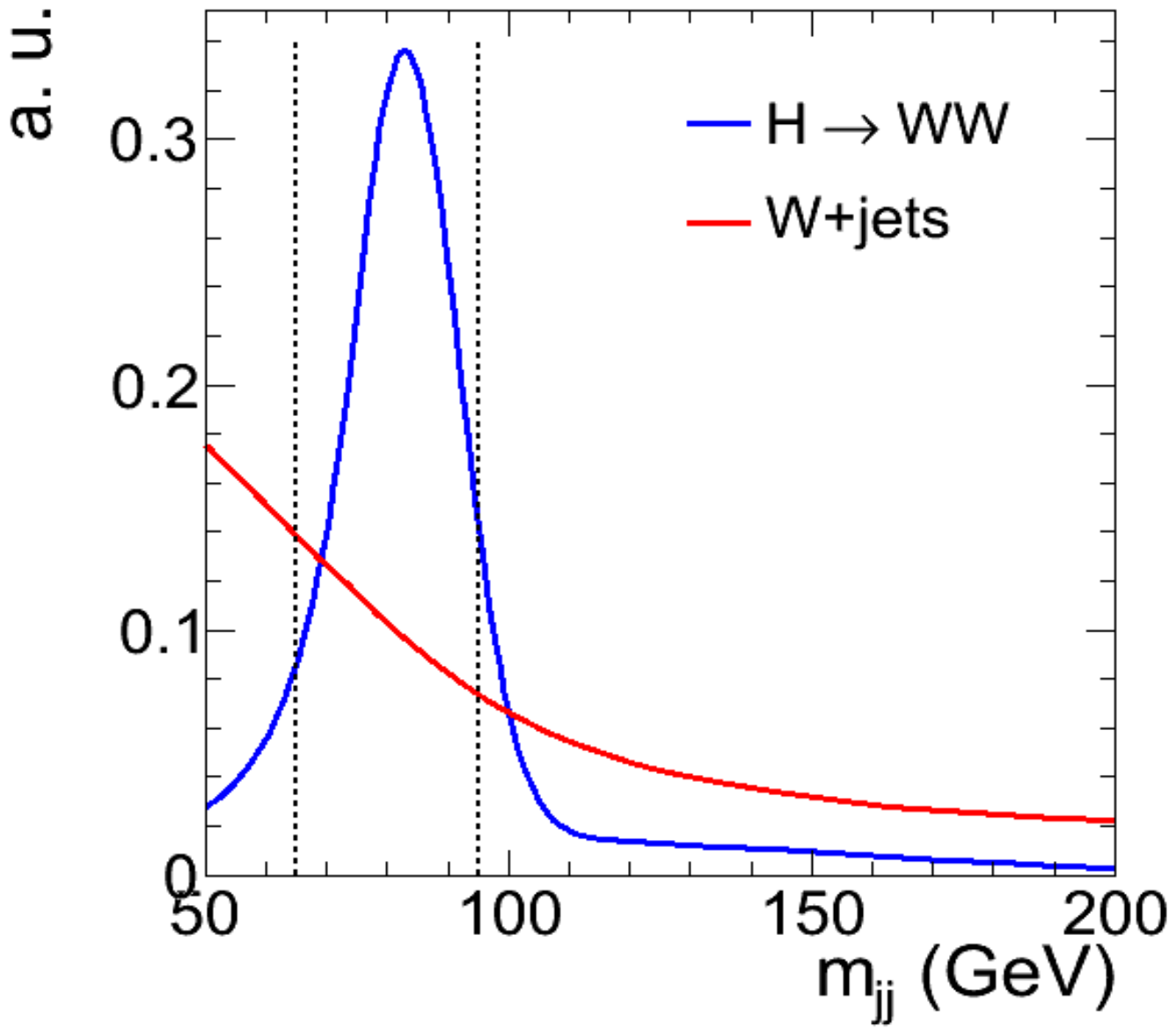


Higgs production rate at LHC

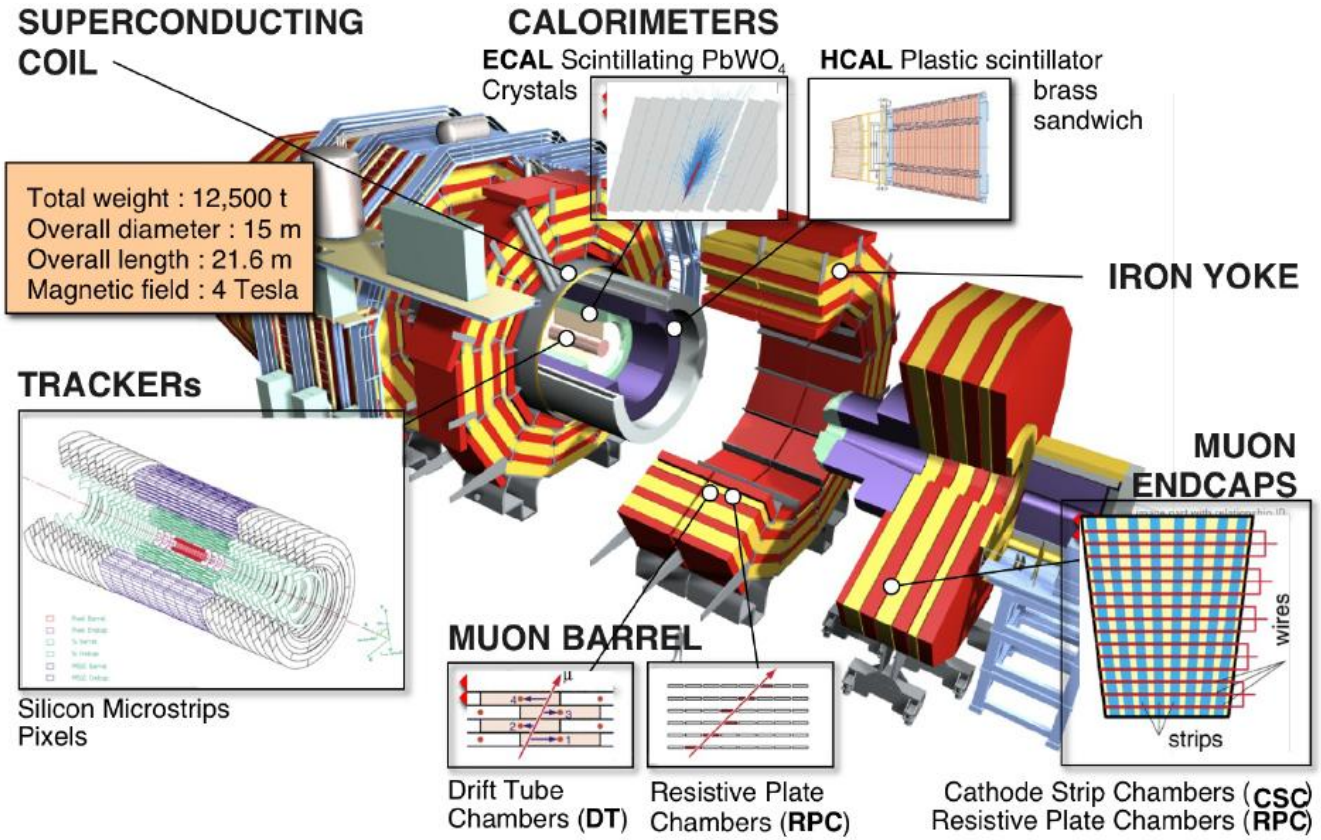


Higgs production time BR




a. u.
0.3
0.2
0.1
0
50
100
150
200
m_{jj} (GeV)
H → WW
W+jets

CMS Detector and Object reconstruction



Jets **are reconstructed from calorimeter and tracker information using a particle flow algorithm.**

Muons **are measured with the tracker and the muon system.**

Electrons **are detected as tracks in the tracker pointing to energy clusters in the ECAL**

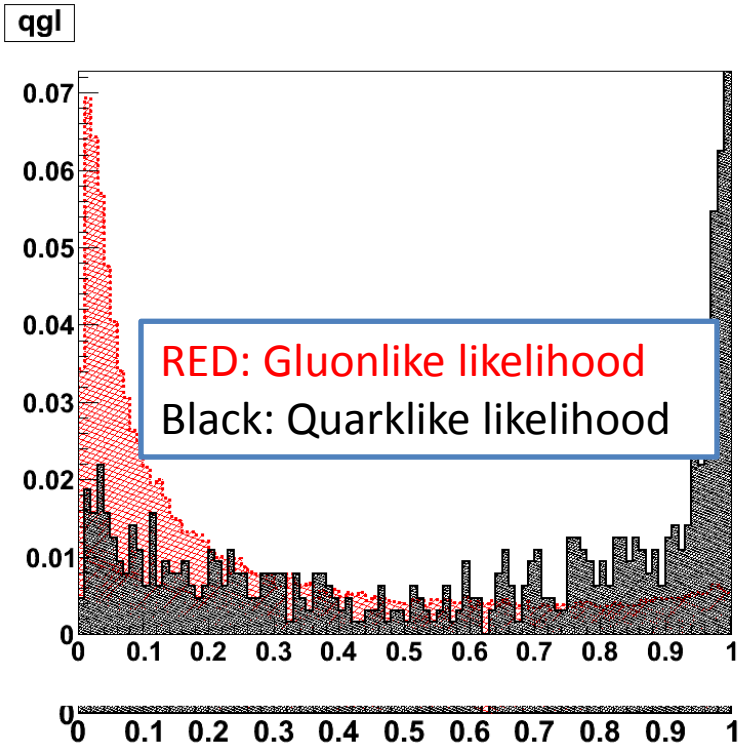
Quark Gluon Likelihood

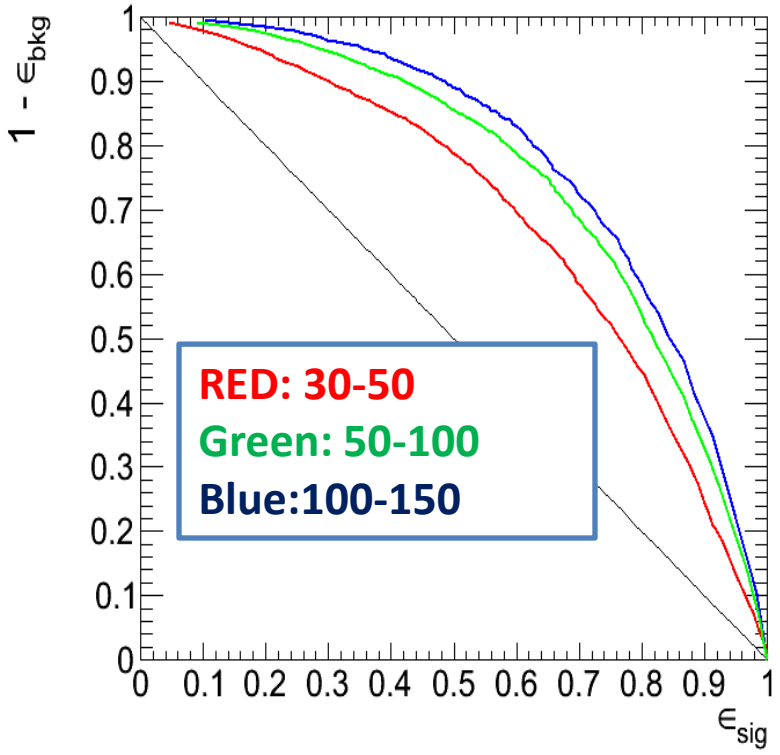
quark flavors uds only, chs flag True, anti-btagged CSV medium

a.. the charged particle multiplicity is higher in gluon jets than in light quark jets;

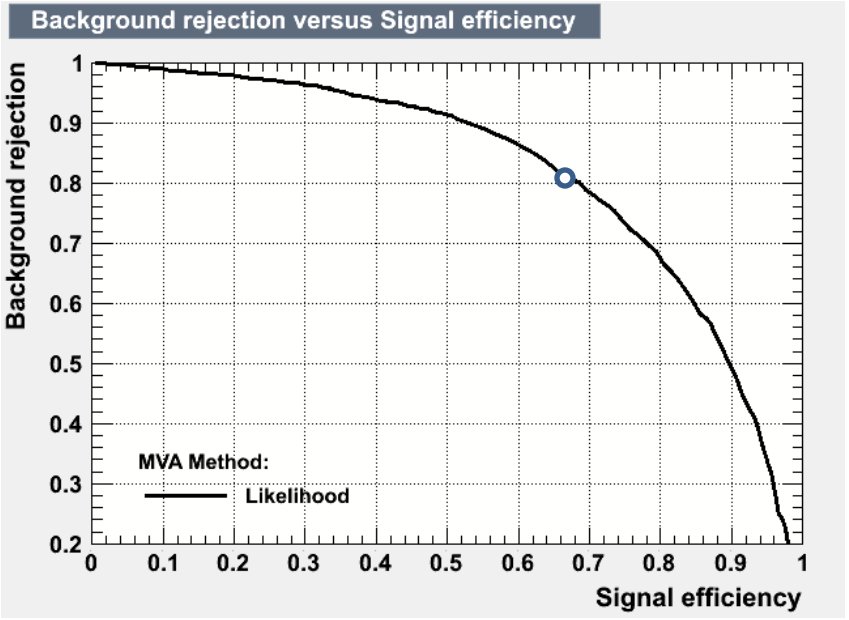
b. the fragmentation function of gluon jets is considerably softer than that of a quark jet;

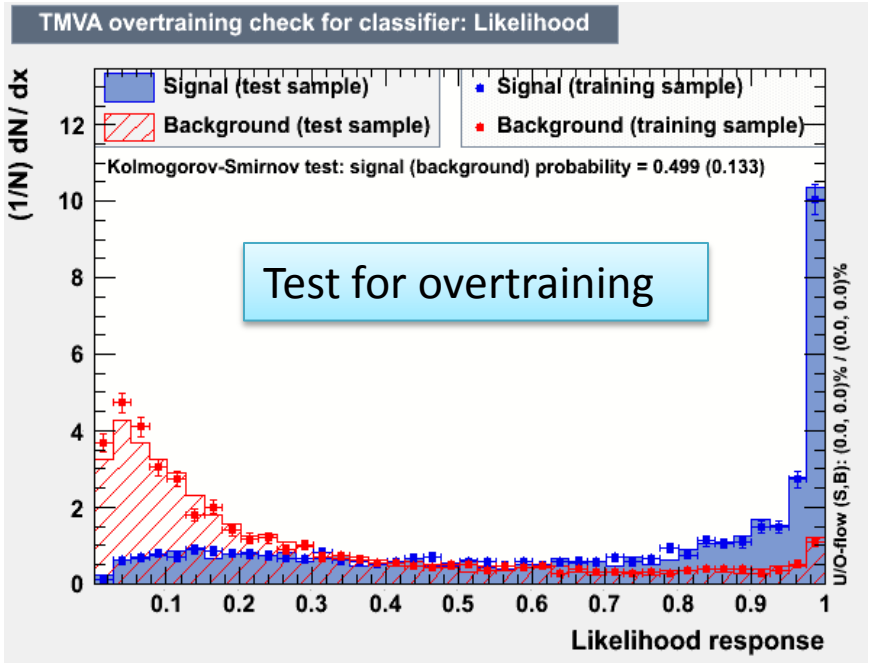
c. gluon jets are less collimated than quark jets.



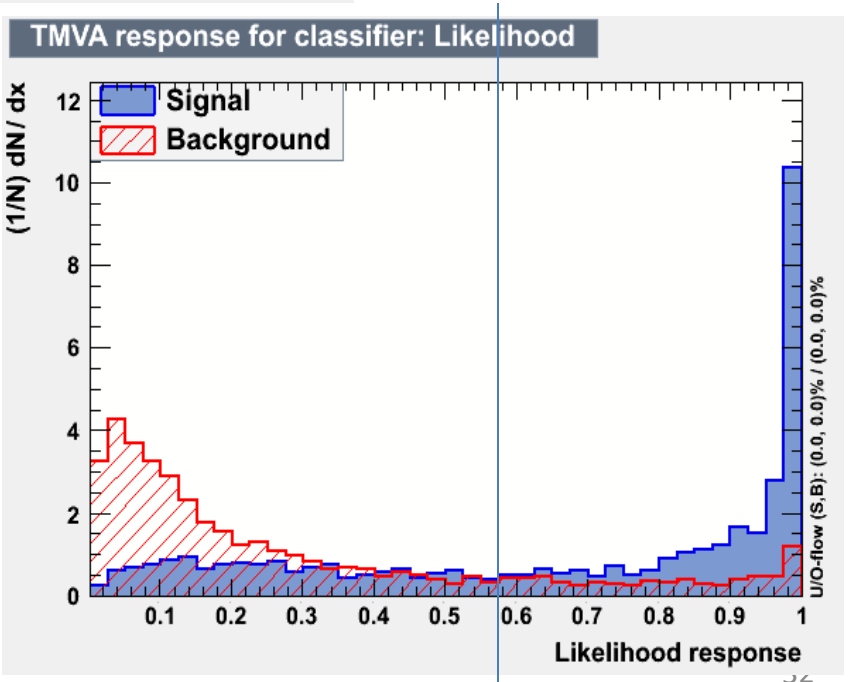


TMVA Likelihood





Test for overtraining



B-tagging in CMS

b quark jet have long life time, high mass and large momentum fraction of the hadron .

B-tagging associates a single, real number - a discriminator - with each jet. B quark (light quark) initiated jets will always tend to show higher (lower) values of the discriminator

Combined secondary vertex (CSV):This sophisticated and complex tag exploits all known variables, which can distinguish b from non-b jets. Its goal is to provide optimal b tag performance, by combining information about impact parameter significance, the secondary vertex and jet kinematics.

https://twiki.cern.ch/twiki/bin/view/CMSPublic/SWGuideBTagging